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Evaluating the Effectiveness of Using Weather Conditions as a Predictor for Occurrence and Duration of Flight Delays

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1 Introduction

Flight delays due to adverse weather conditions pose significant challenges to the aviation industry. Researchers Christopher J. Goodman and Jennifer D. Small Griswold found that extreme weather events were responsible for 32.6% of the total delay minutes recorded in the National Airspace System (NAS) from 2003 to 2015, with severe weather causing up to 82% of delay minutes in some instances [3]. Such delays have an impact on the environment as well as economic performance in the airline industry. [6, 7, 8]. The annual economic impact of airline delays was estimated by one study to be $31.2 billion in 2010 and $40.2 billion in other estimates [1]. In addition, climate change and air transportation have a reciprocal relationship: aircraft emissions contribute to anthropogenic climate change while atmospheric changes directly impact operations in the airline industry [5]. Not only this–delays due to inclement weather are increasing over time. In comparing the impact of a winter storm in December 2021 versus December 2022, aggregated total passenger "dwell time" in airports saw an increase of approximately 12 million hours [9]. There are several factors contributing to increasing frequency of weather delays and the economic and environmental impacts are substantial; thus, the ability to accurately predict the occurrence and duration of flight delays and manage these disruptions is increasingly crucial. This study aims to answer the following question: does the use of weather conditions as a predictor increase the accuracy of existing models that classify flight delays and allow us to estimate their duration?

Previous studies have highlighted the interaction between meteorological conditions and aviation operations, employing various Machine Learning (ML) and data-driven approaches to forecast delays [2, 3, 4]. These findings emphasized the importance of understanding weather patterns and airport-specific vulnerabilities to optimize flight schedules and improve operational efficiency. A group of researchers, Kerim Kiliç and Jose M. Sallan, examined arrival delays across the United States airport network using a variety of models [4]. Their analysis, based on 2017 flight and weather data, found the Gradient Boosting Machine (GBM) model to be the most effective. Although their study covered a larger geographic area, it mainly focused on classifying delays and faced challenges with imbalanced data and limited real-time data use. In a study conducted in 2024, Seongeun Kim and Eunil Park expanded the scope by applying a wider suite of ML models to predict departure delays at three major international airports [2]. Their models achieved high predictive accuracy, with rates of 0.749 for Incheon (ICN), 0.852 for John F. Kennedy (JFK), and 0.785 for Chicago Midway (MDW) in 2-hour forecasts. Although their study demonstrated the potential of ML models in long-term delay predictions, it was limited by its focus on individual airports and a reliance on historical datasets from 2011 to 2021, which may not fully capture future or emerging trends in weather patterns. In a similar study, Sun Choi and others also trained ML models with the goal of classifying whether a flight was delayed or on-time due to weather conditions. Their highest accuracy percentage was 80.36% using the Random Forest (RF) classifier [10]. Each of these studies focused on a binary classification model in which the aim was to classify a delayed or on-time flight due to various weather conditions without seeking to estimate the duration of the delays. Though several studies have been conducted in which delay classification prediction was explored, the scope of the datasets and the use of regression models has been limited.

Building on these foundational studies, our research aims to address the limitations of previous work by integrating recent, high-frequency data across a more diverse range of U.S. airports. Unlike previous studies that focused on single airports or had limited data, we used advanced model selection and real-time data integration to improve prediction accuracy and generalizability. We compared the accuracy of classification and regression models in three scenarios: (1) when weather conditions aren't used as an independent variable, (2) when they're used in conjunction with flight data as independent variables, and (3) when weather conditions are used as an independent variable without flight data. By using this approach, we aim to determine if weather conditions are an effective predictor for precise models with a high level of accuracy in predicting flight delays. In developing models that account for the dynamic interactions between weather conditions and flight delays, we seek to provide stakeholders with actionable insights to reduce delay-related costs, environmental impacts, and improve overall passenger satisfaction. This research will not only advance the current state of delay prediction but also contribute to the broader field of transportation analytics, offering scalable solutions for mitigating weather-related disruptions across various modes of transportation. We believe that by using our diverse high-frequency dataset this study will find that weather conditions are an invaluable explanatory variable when it comes to classifying and predicting the duration of flight delays.

2 Sources

Having a valid and reliable source to find data for a ML project is essential. One of our main goals for this project is to determine the effectiveness of weather data as a predictor for flight delays. To carefully find the relationship between weather and flight delays, we needed a dataset that contained both the weather data and the flight data. However, after exploring online resources for such data, we found that this kind of dataset does not exist. The subsequent alternative to finding the data was to find one source for weather data and one for flight data, and then combine them.

We found the Department Of Transportation (DOT) a credible source for flight data. The website allowed us to extract many important variables related to flight information such as flight date, time, airport identification number, departure time, and the number of minutes the flight is delayed (difference in minutes between scheduled and actual departure). The predictors from the flight data we'll be using include variables such as month and year, origin and destination, time of day, airline, and airport. We created a binary column that indicates if a flight has been delayed for 5 minutes or longer which we'll use as the classification response variable. The column containing the number of minutes the flight has been delayed will be used as the response variable for our regression model.

Although numerous sources exist to find weather data such as Weather Underground and National Oceanic and Atmospheric Administration (NOAA), we found Iowa Environmental Mesonet (IEM) a reliable source for collecting the weather data. We found this source credible for the following two reasons. First, IEM solely focuses on airport weather data, not only in the US but also at airports around the world, which can inform future work by applying the findings of this paper to global datasets. Secondly, IEM extracts the data through the Automated Surface Observing System and according to the IEM website, "ASOS networks are nationally monitored for quality 24 hours per day". This adds another level of confidence and surety to the validity and reliability of the data. The predictors from the weather data we'll be using include variables such as air temperature, dew point temperature, wind speed, wind direction, visibility, and pressure. We included weather and flight data of all the airports from 10 different states including: Florida, Texas, Colorado, New York, Illinois, California, Georgia, New Jersey, Maryland and Nevada between the years of 2014 and 2024.

After conducting a comprehensive literature review, we identified the key concerns and how different researchers approached weather-related flight delays. Almost all of the literature reviews have been published in the past 5 years which is very relevant to our research. The oldest one goes back to July 2007, which is still relevant today, but this paper only talks about the environmental impacts of flight delays. The studies that we have used as our sources have been published in credible journals in the fields of aviation, aerospace, and meteorology which are all essential fields of studies to understand the complex relationship between weather and flight delays. Not only that, most of our sources have been published by the most credible scientific publishers such as Springer and Cambridge University Press. These interdisciplinary publications provide us with a strong foundation on past work completed in this field and ensure the reliability and validity of our sources.

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